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PDF issues in EW precision measurements

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Brookhaven, April 4th 2013

Impact of PDF uncertainties of EW precision measurements

- the extraction of masses and couplings, at hadron colliders, relies on a template fit procedure

- the uncertainties/ambiguities that affect the evaluation of the templates are theoretical systematics on the final value of the pseudo-observables that we want to extract

- the use of different PDF replicas yields in general a distortion of the template shapes and in turn a different value of the pseudo-observable

- are PDFs a limiting factor?

- can we use LHC data to improve the PDFs and to reduce their impact on precision measurements?
  → reweighting technique for a quick estimate of the role of new available data

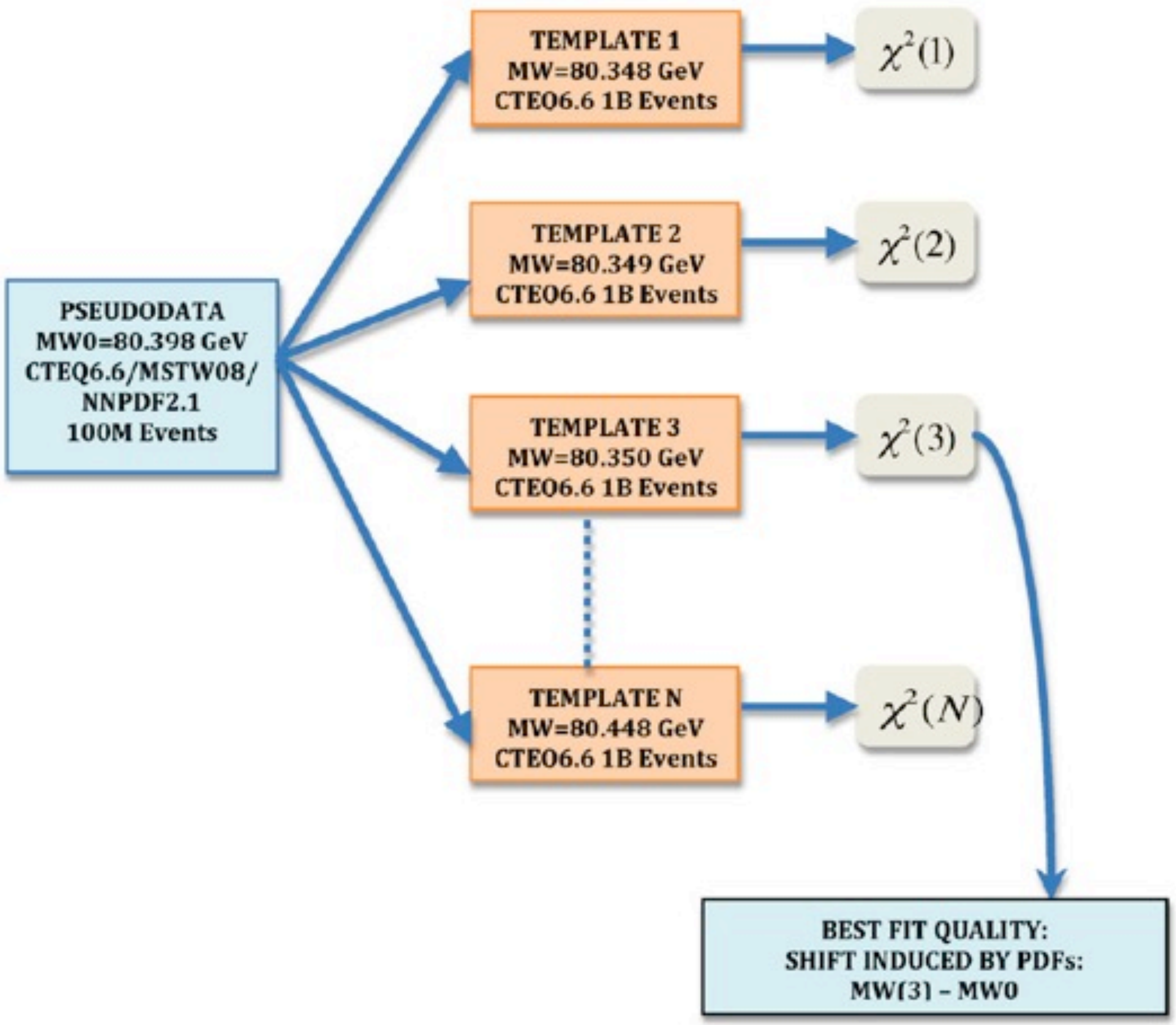
- search for correlations (w.r.t. PDFs) between all the available EW observables
  → can we build ratios of observables with reduced PDF uncertainty still sensitive to the EW parameters?

Plan of the talk

- template fit technique to estimate the PDF impact on the measurement of MW: transverse mass case
- reweighting technique to include and to estimate the effect of new LHC data
- systematic search for correlations, to exploit the richness of LHC data in terms of information directly and indirectly useful for precision EW measurements

Estimate of the error on MW induced by the PDFs (G. Bozzi et al, arXiv:1104.2056)

- each PDF replica is used to generate a set of pseudodata, with a fixed value MW_0
- a very accurate set of template distributions has been prepared, varying only MW, with a reference(CTEQ6.6) PDF replica
- when pseudodata generated with the reference replica are fitted, the nominal value MW_0 is found (sanity check)
- the same code, DYNNLO, has been used to generate both, pseudodata and templates → only effect probed is the PDF one



- the MW shift expresses the distance between the PDF replica under study and the reference replica
- the PDF error is obtained combining the different MW results from each replica, according to the formulae recommended by the PDF collaborations

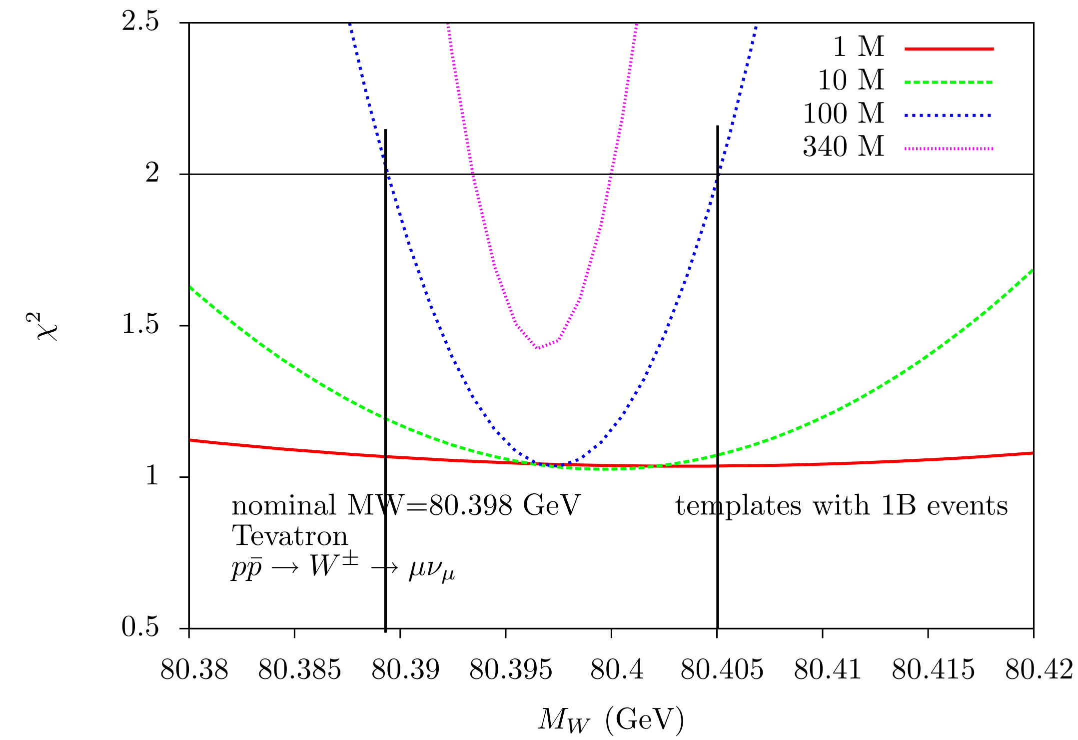
Comments on the template-fitting procedure

Fit pseudo-data computed in the same approximation, with same parameters of the templates

The fit should exactly find the nominal value MW_0 used to generate the pseudo-data (reduced $\chi^2 \sim 1$)

The accuracy of the fit depends on the error associated to each bin of the pseudo-data

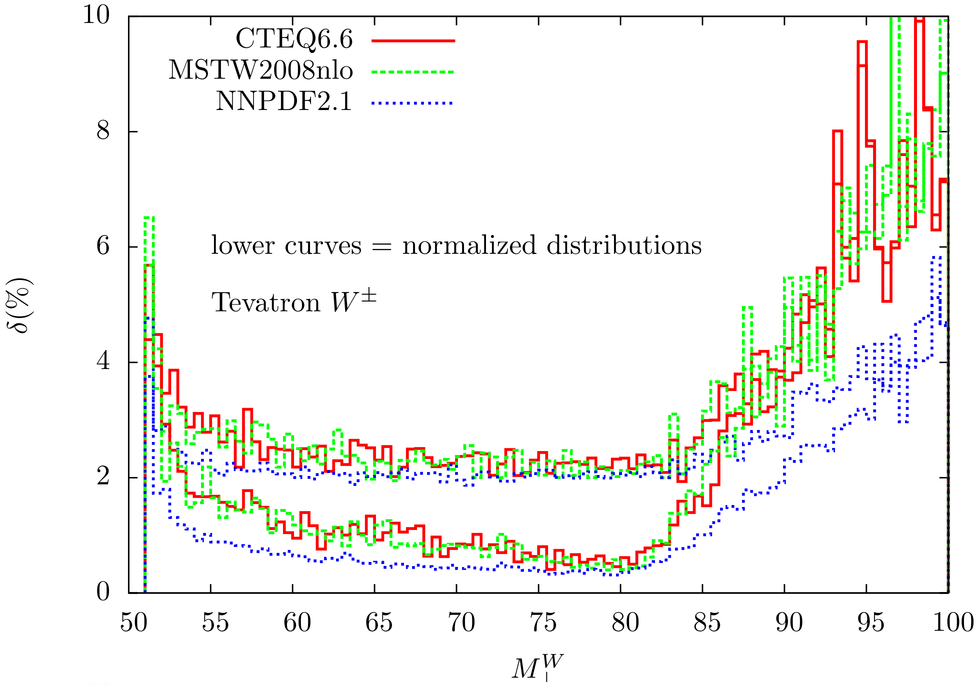
In the validation test,
the $\Delta\chi^2 = 1$ MW points fix the 68% C.L. interval associated to the estimate of the preferred MW.



When the pseudodata have a shape different than the one of the templates, the reduced χ^2 is never close to one because the distributions are "by construction" different

When the shapes compared are sensibly different, the fitter is pulled towards values
very different than the nominal one
the fitter tries to compensate the shape difference, with a large adjustment of MW

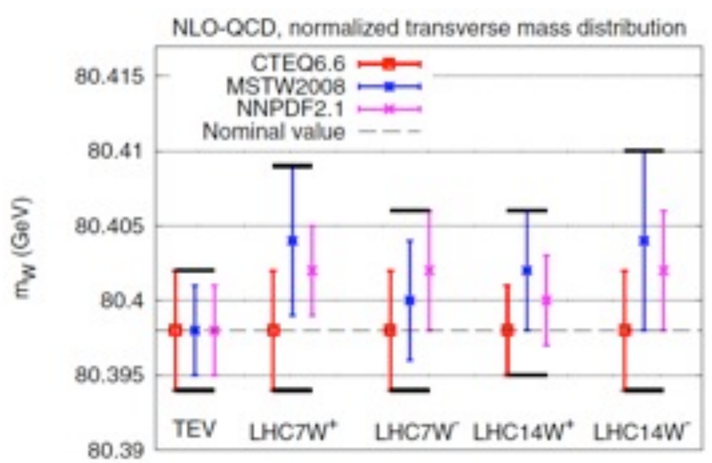
PDF error on MW from transverse mass distribution



- the PDF effect on MW is obtained by studying the transverse mass normalized distributions: different PDF normalization should not be accounted for by a MW shift

- the templates and the pseudodata are computed with the same generator in the same experimental setup: in first approximation the PDF effects factorize w.r.t. all the other theoretical and experimental factors

	CTEQ6.6		MSTW2008		NNPDF2.1		
	$m_W \pm \delta_{\rm pdf}$	$\langle\chi^2\rangle$	$m_W \pm \delta_{\rm pdf}$	$\langle\chi^2\rangle$	$m_W \pm \delta_{\rm pdf}$	$\langle\chi^2\rangle$	$\delta_{\rm pdf}^{\rm tot}$
Tevatron, $W^\pm$	80.398 ± 0.004	1.42	80.398 ± 0.003	1.42	80.398 ± 0.003	1.30	4
LHC 7 TeV W^+	80.398 ± 0.004	1.22	80.404 ± 0.005	1.55	80.402 ± 0.003	1.35	8
LHC 7 TeV W^-	80.398 ± 0.004	1.22	80.400 ± 0.004	1.19	80.402 ± 0.004	1.78	6
LHC 14 TeV W^+	80.398 ± 0.003	1.34	80.402 ± 0.004	1.48	80.400 ± 0.003	1.41	6
LHC 14 TeV W^-	80.398 ± 0.004	1.44	80.404 ± 0.006	1.38	80.402 ± 0.004	1.57	8



- the accuracy of the templates, to avoid spurious fluctuations, is very important because many effects are of O(5 MeV): it is a highly demanding task from the computational point of view, already at NLO-QCD

- for the transverse mass distribution, a fixed order NLO-QCD analysis is sufficient to assess this uncertainty

- if confirmed, the PDF error is moderate at the Tevatron, but also at the LHC, even before the use of the LHC data

Reduction of the PDF uncertainty on MW measurement

two possible strategies (similar in their physical content):

1) use a large set of observables
including also data NOT sensitive to MW
to exploit the possible PDF correlations with the observables that ARE sensitive to MW
(e.g. building ratios that implement some cancellations)

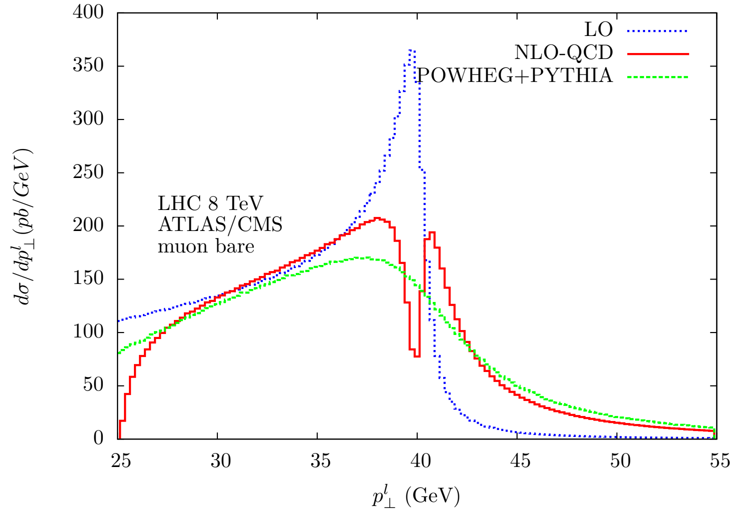
2) improve the PDFs with a new global fit that includes all the available LHC results:
- ideally a new fit that includes at differential level all the new LHC measurements;
  in practice, we need to understand which measurements can be most useful to reduce specifically the uncertainties affecting MW
- in the short term, we can test the validity of our guesses by applying a reweighting procedure to existing PDFs, checking that a significant reduction of the error is achieved
  in the long term, the relevant data can be included in a full global fit

in both cases, one needs to analyze at differential level
- which parton luminosities are responsible for the PDF uncertainty on MW
- which ranges of *x* and of the final state invariant mass are probed

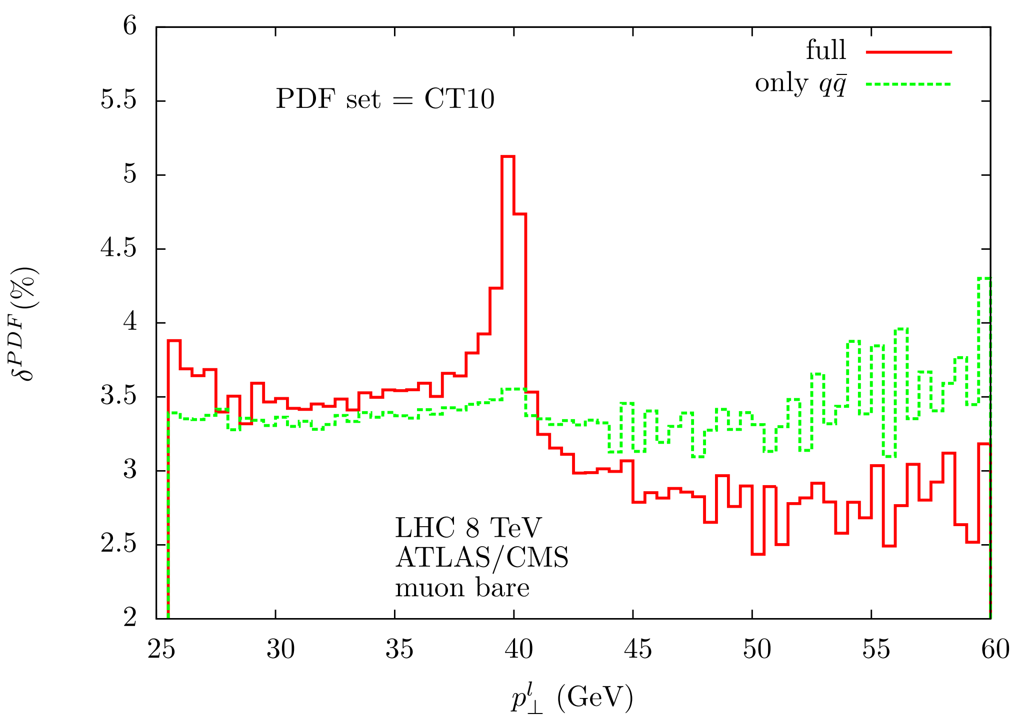
$$\sigma(P_1, P_2; m_H) = \sum_{a,b} \int_0^1 dx_1 dx_2 \, f_{h_1,a}(x_1, M_F) f_{h_2,b}(x_2, M_F) \, \hat{\sigma}_{ab}(x_1 P_1, x_2 P_2, \alpha_s(\mu), M_F)$$

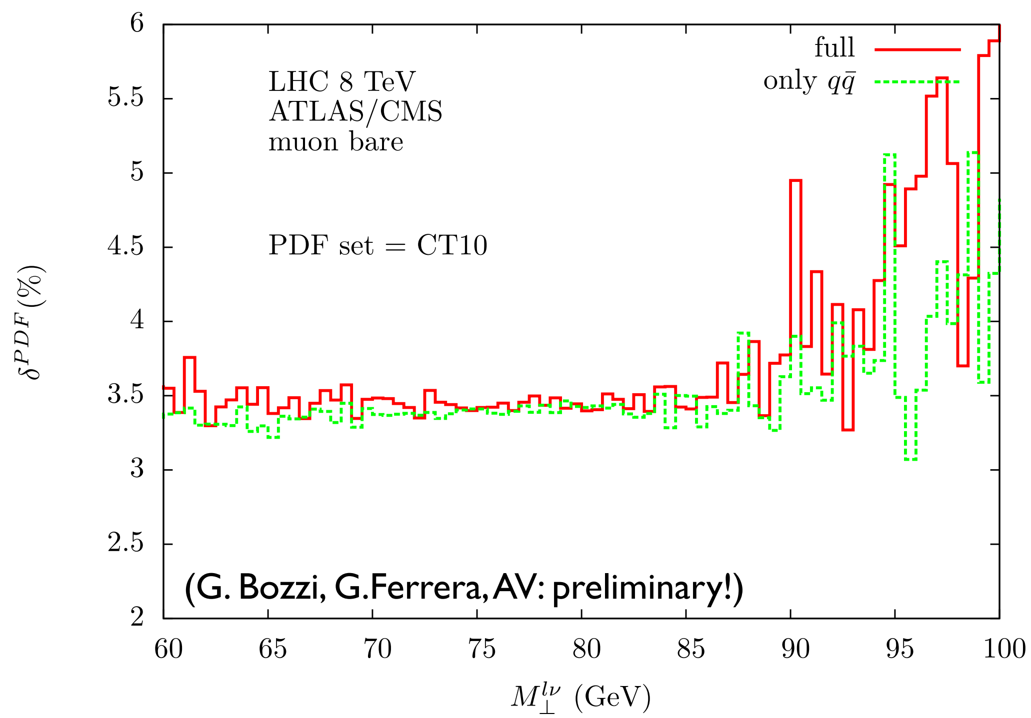
PDF error on MW from lepton transverse momentum distribution

- the lepton transverse momentum distribution is sensitive to the details of QCD radiation



- at NLO-QCD gluon-quark subprocesses yield an important contribution
  → the gluon PDF uncertainty is more pronounced than in the transverse mass case



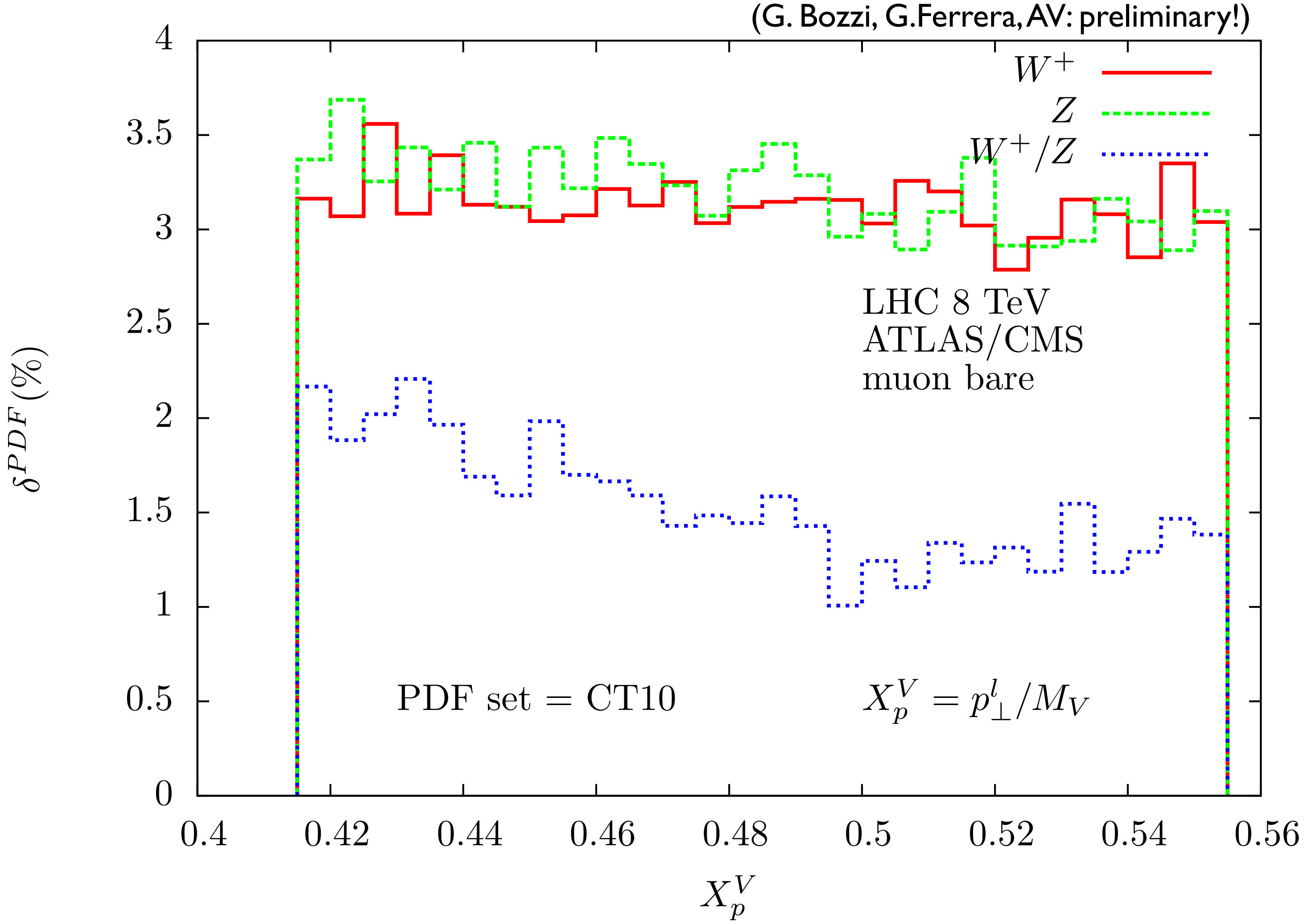


caveat: 1) the above uncertainties have been computed with DYNNLO at NLO-QCD
2) only the full process has a well defined physical meaning

PDF error on MW from lepton transverse momentum distribution

a preliminary study with DYqT shows that it is possible to partially get rid of the PDF uncertainty (e.g. of the quark-gluon luminosity)
by studying appropriate ratios of observables
which should preserve the sensitivity to MW (in progress)

(G. Bozzi, G.Ferrera, AV: preliminary!)



$$\frac{d\sigma}{dX_p^V}$$

these results are obtained with the resummation with (LO+NLL)-QCD accuracy including the gluon-induced subprocesses

the W+ distribution is sensitive to MW (jacobian peak corresponding to Xp=0.5)

the Z distribution is weakly sensitive to MW (couplings), but probes similar *x* PDF ranges

Inclusion of LHC data via reweighting (NNPDF)

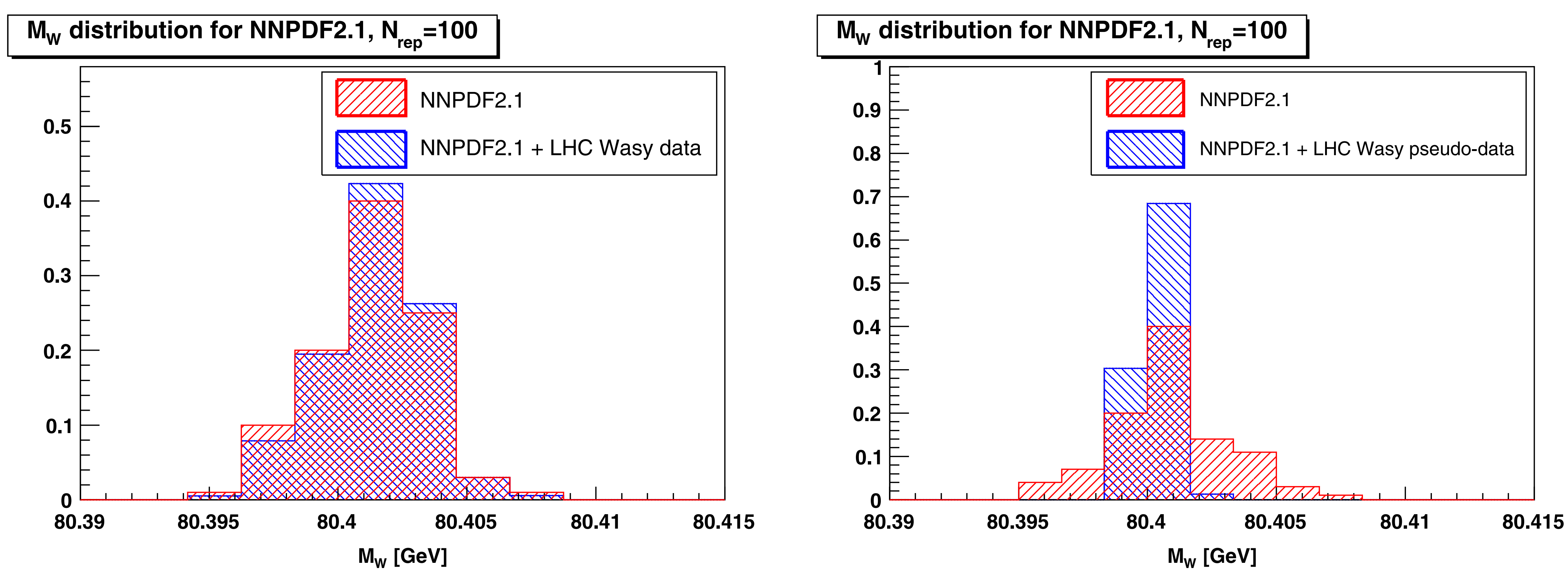
- the existing PDF replicas can be classified by measuring how well they describe new LHC data i.e. the new data indicate which replicas (based on older data) are favored/disfavored

  from the comparison with new data, a weight is associated to each PDF replica

$$w_k \propto \chi_k^{n-1} e^{-\frac{1}{2}\chi_k^2}$$

  where the χ^2 is computed from the new data set containing *n* points

- this weight is then used in the evaluation of the PDF spread on any other observable (like MW)



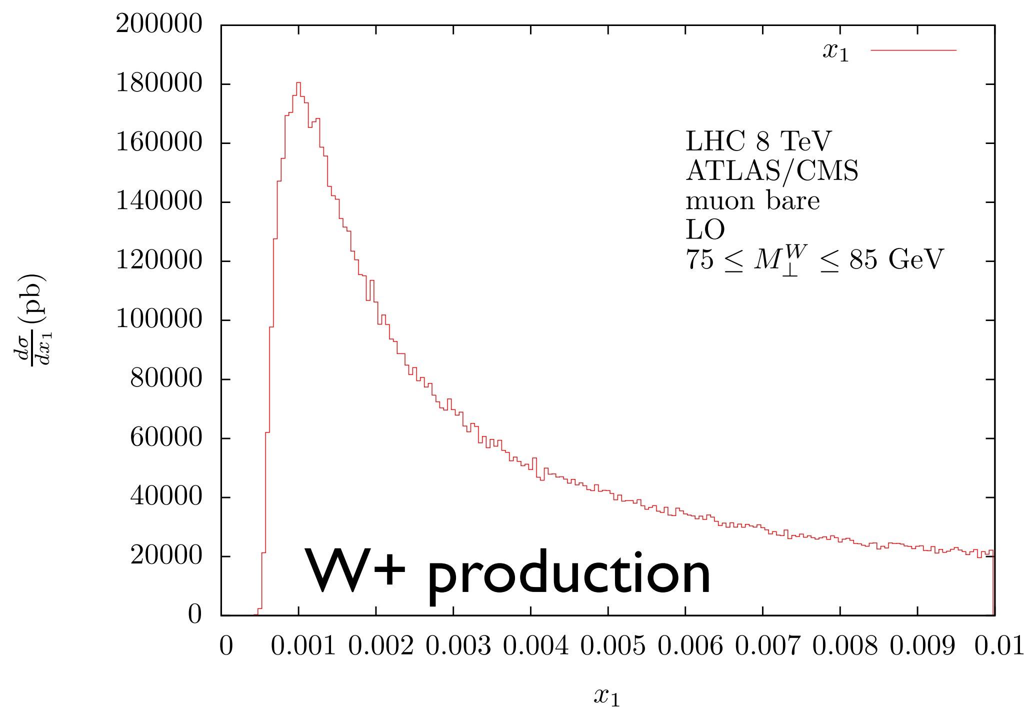
more details about the evaluation of weights with multiple data sets in arXiv:1108.1758 (NNPDF)

Which observables can help?

- total cross section (ATLAS/CMS central cuts) LHC 8 TeV, LO

W+ production		W- production	
u-dbar	79.5%	d-ubar	71.5%
c-sbar	16.1%	s-cbar	24.0%
u-sbar	3.3%	d-cbar	2.5%
c-dbar	1.1%	s-ubar	2.0%

- distribution of partonic *x*, in a range relevant for MW measurement



- W charge asymmetry
- W+charm production
- NC-DY invariant mass and inv.mass AFB

with cuts selecting the relevant *x* range

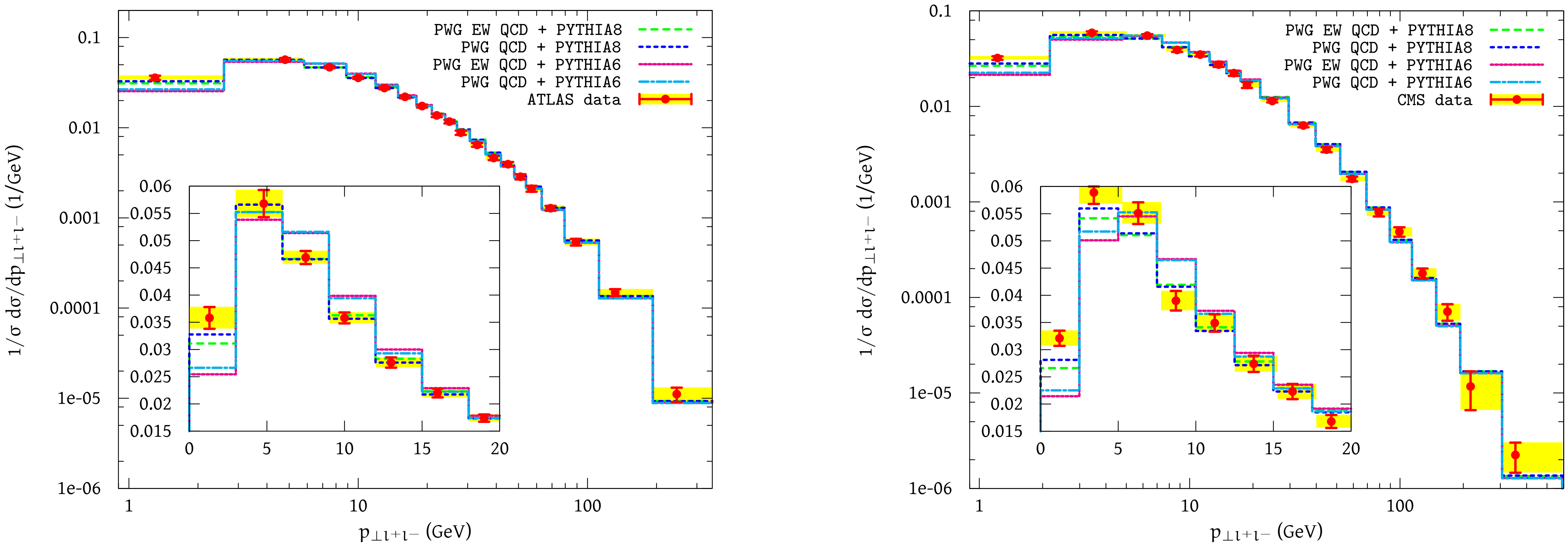
PDF error on MW from ptW distribution

The determination of the transverse mass distribution

$$M_\perp^W = \sqrt{2 p_\perp^l p_\perp^\nu \, (1 - \cos\phi_{l\nu})}$$

requires an accurate modeling at low momenta of the ptW distribution,
which depends also on a non-perturbative QCD ISR component that contributes to the recoil of the lepton pair.

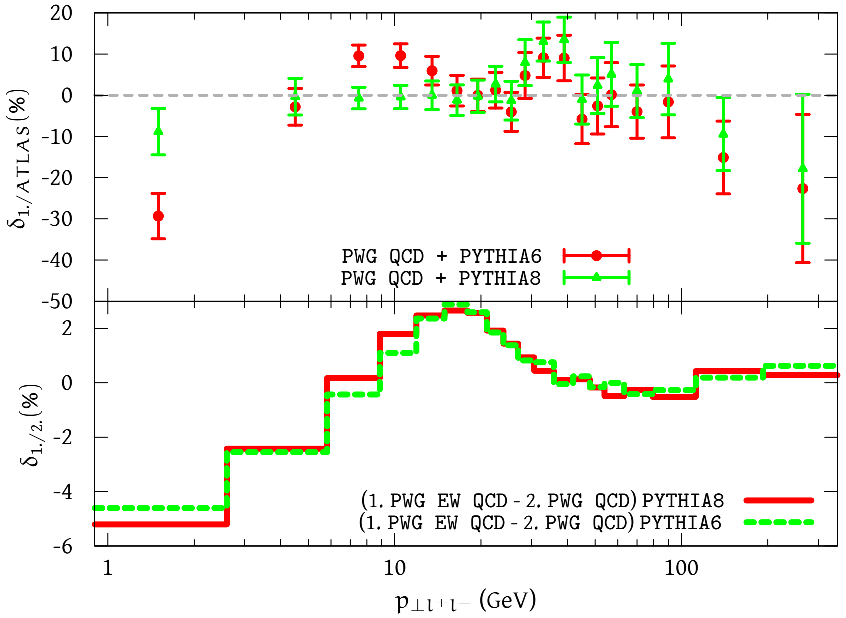
Barzè, Montagna, Nason, Nicrosini, Piccinini, Vicini, arXiv:1302.4606

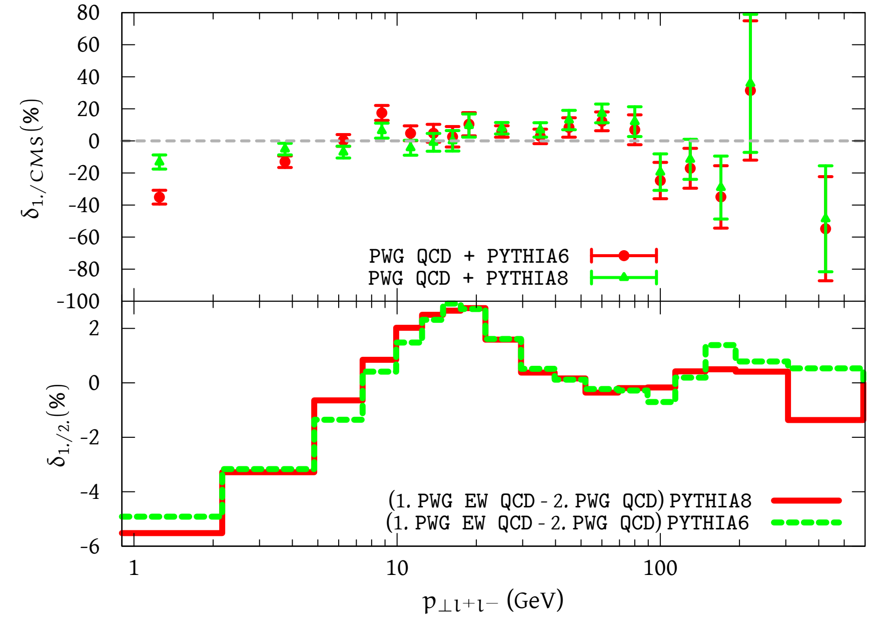


- the description of the lepton-pair transverse momentum distribution data is in general good
- in the plots showing POWHEG NLO (QCD+EW) results,
  default values for the non-perturbative parameters in PYTHIA6 and PYTHIA8 have been used (further tuning possible)
- how does the tuning of non-perturbative parameters depend on the PDF choice?

NC-DY: QCD+EW effects lepton-pair transverse momentum

Barzè, Montagna, Nason, Nicrosini, Piccinini, Vicini, arXiv:1302.4606





- full NLO-EW matrix element → bulk of the QED effects on ptZ; multiple photon radiation has negligible impact

- QED radiation affects differently ptW and ptZ, both in its FSR and in its ISR components
  POWHEG (QCD+EW) for CC- and NC-DY allows to disentangle the different QED effects
  from the common pattern of the QCD corrections

- the uncertainty on MW stemming from PDFs, from the modeling of the non-perturbative component of ptW and from ISR QED effects are related questions to be discussed in the same framework

- for consistency, a photon density is necessary in the description of the proton:
  available is MRST2004QED
  in Moriond 2013 NNPDF presented a preliminary exercise for a NNPDF23-QED

- constraints on the photon density may come from an accurate measurement of low invariant mass and of high invariant mass NC-DY

Comments and to-do list

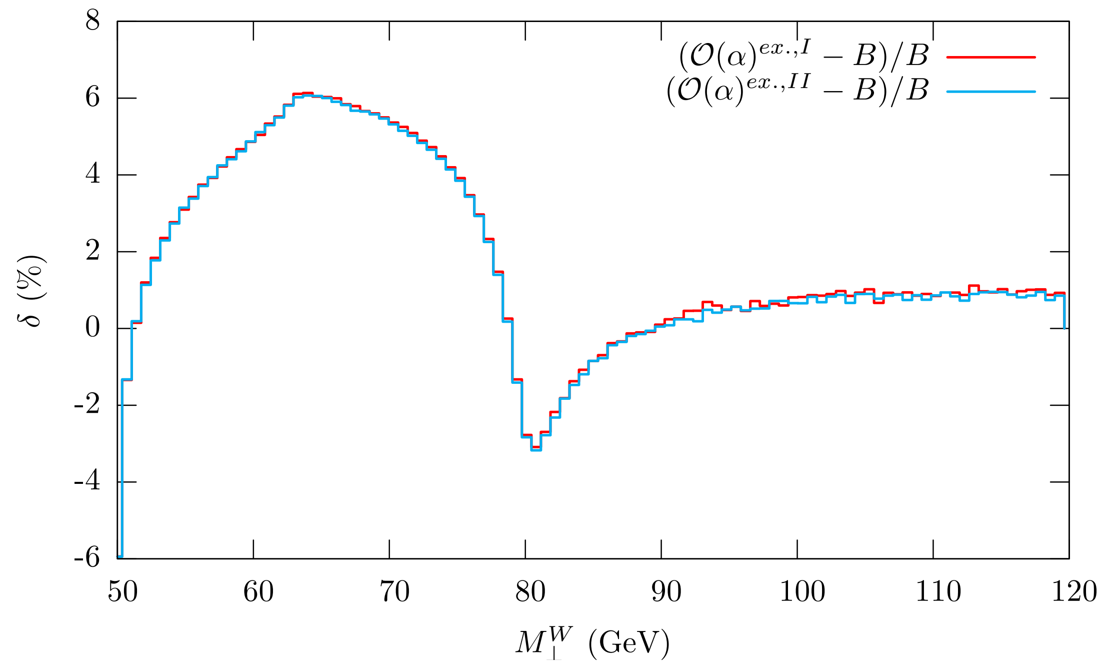
- the template-fit technique provides a clear procedure to assess the impact of PDFs on precision EW measurements,
  but it is quickly very demanding from the point of view of CPU, when higher-order QCD corrections are included
  it has its own intrinsic uncertainty

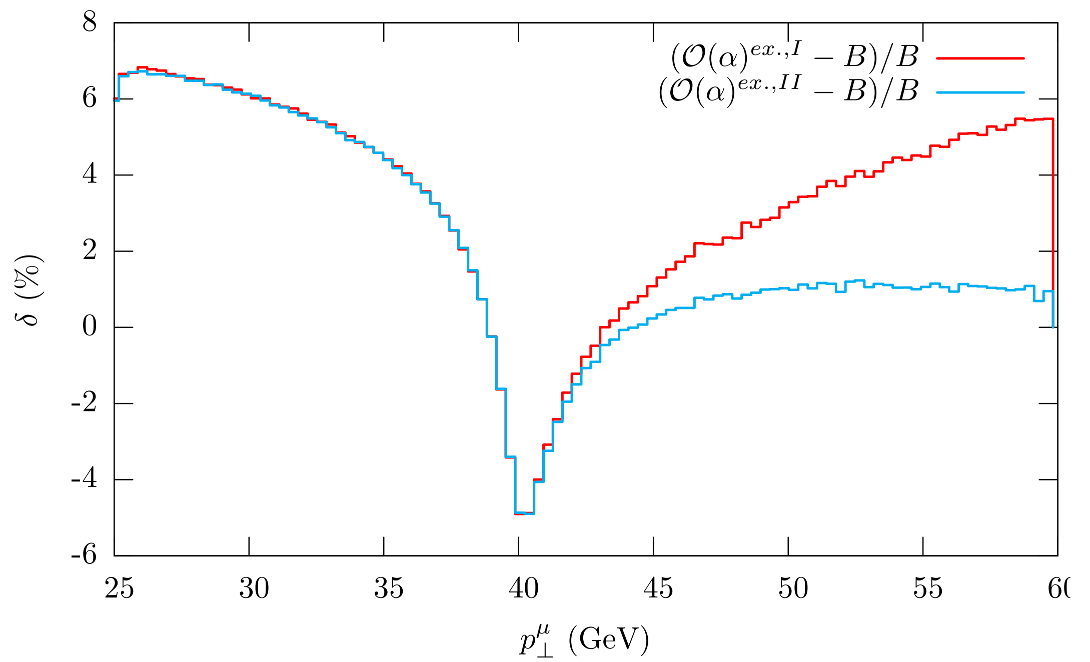
- we need
  - a systematic study of all the correlations between all the parton luminosities and all the available hadron collider observables;
    it can provide a useful indication of which data (not only DY) are relevant to reduce the PDF impact on high precision measurements
  - a systematic differential study to break the total PDF uncertainty to MW into contributions associated to specific values of partonic *x*
    ptW
    final state invariant mass (only theoretical)
  - a systematic tuning of the non-perturbative param's of NLO-Shower Montecarlo
    its impact should be quoted together with the PDF uncertainty
  - an assessment of the role of QED-PDFs in the global improvement of the PDFs for MW

- starting from high-mass DY and from the high-mass AFB
  study the limitations on the searches for new physics signals due to PDF uncertainties at large-*x*

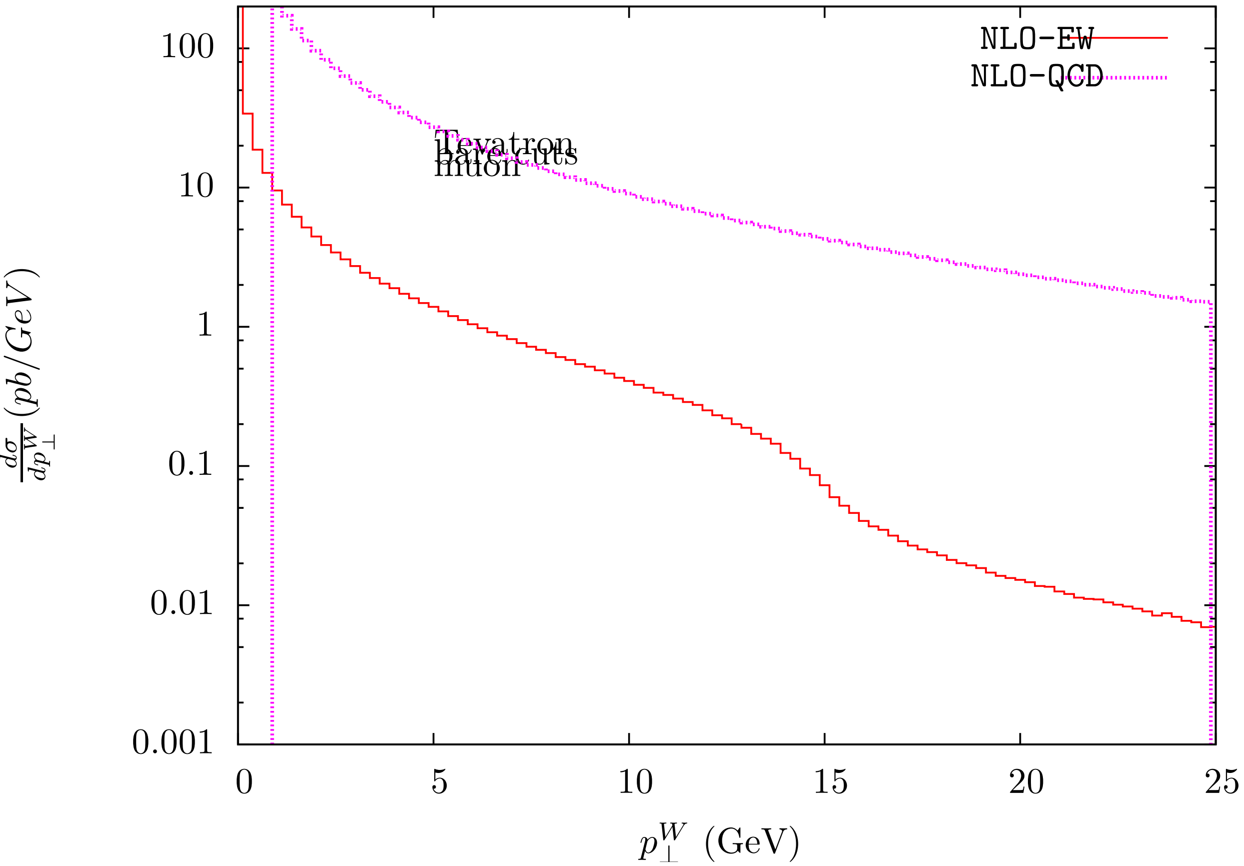
Back-up slides

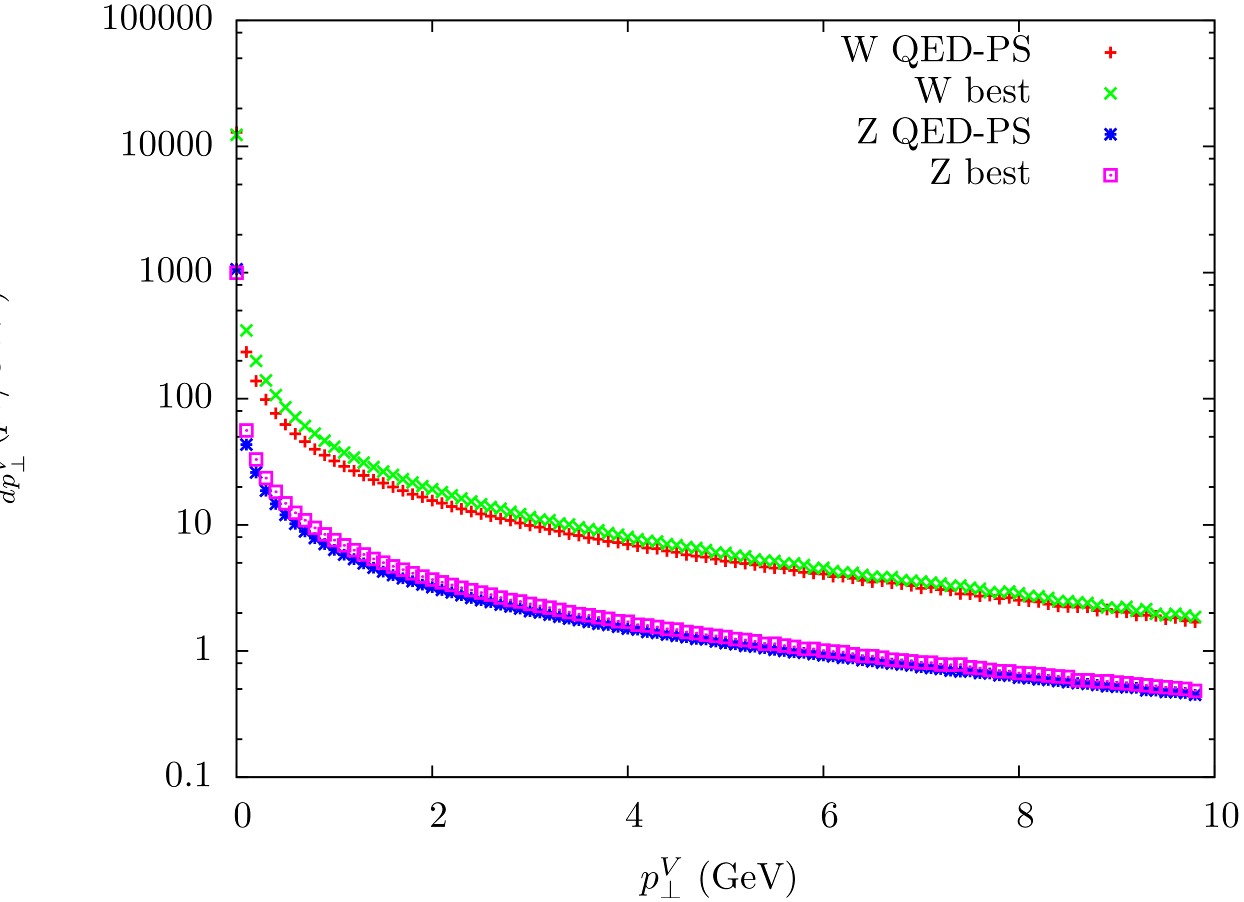
Impact of photon-induced processes on the distributions relevant for the MW extraction





QED induced W(Z) transverse momentum





The uncertainty on ptW directly translates into an uncertainty on the final MW value.

Photon radiation yields a tiny gauge boson transverse momentum.

This momentum is different in the CC and NC channels because of the different flavor structure.

A possible estimate of the "non-final state" component differs in the 2 cases by 54 (Z) - 33 (W) = 21 MeV

$$\langle p_\perp^V \rangle =$$

Z	FSR-PS	0.409	GeV
Z	best	0.463	GeV
W	FSR-PS	0.174	GeV
W	best	0.207	GeV

The fit of the non perturbative QCD parameters is done on the Z transverse momentum and it is necessary to properly remove the EW corrections to the NC channel

In the simulation of the CC channel the relevant EW corrections are then applied

Impact of PDF uncertainties on sin2thetaW measurement

$$A_{FB}(M_{l^+l^-}) = \frac{F(M_{l^+l^-}) - B(M_{l^+l^-})}{F(M_{l^+l^-}) + B(M_{l^+l^-})}$$

$$F(M_{l^+l^-}) = \int_0^1 \frac{d\sigma}{d\cos\theta^*} d\cos\theta^* \qquad B(M_{l^+l^-}) = \int_{-1}^0 \frac{d\sigma}{d\cos\theta^*} d\cos\theta^*$$

$$\cos\theta^* = f \frac{2}{M(l^+l^-)\sqrt{M^2(l^+l^-) + p_t^2(l^+l^-)}} [p^+(l^-)p^-(l+) - p^-(l^-)p^+(l^+)]$$

$$p^\pm = \frac{1}{\sqrt{2}}(E \pm p_z) \qquad f = \frac{|p_z(l^+l^-)|}{p_z(l^+l^-)}$$

- At $Y_Z = 0$, A_{FB} is exactly zero: LHC is a symmetric collider (pp) and the asymmetry of q-qbar and qbar-q initiated processes cancels

- At large Y_Z , the different weight of q-qbar and qbar-q initiated processes leaves a residual asymmetry: the larger Y_Z , the more pronounced A_{FB}

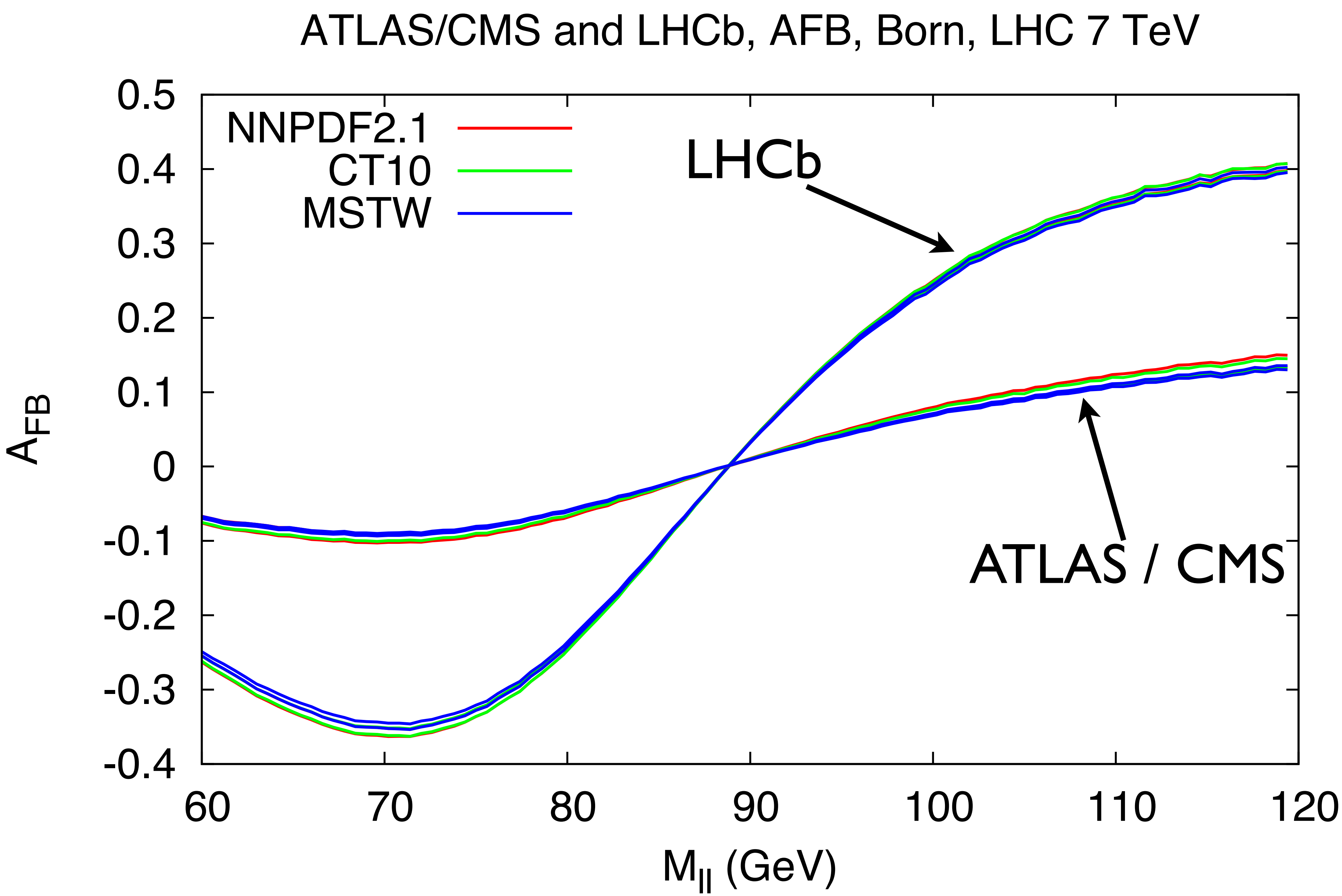
- The asymmetry is due to the difference between valence and sea components of the quark densities

Impact of PDF uncertainties on sin2thetaW measurement

acceptance cuts: $p_\perp^l > 25\,\mathrm{GeV}$

ATLAS / CMS $|\eta_l| < 2.5$

LHCb $2.0 < \eta_l < 4.5$

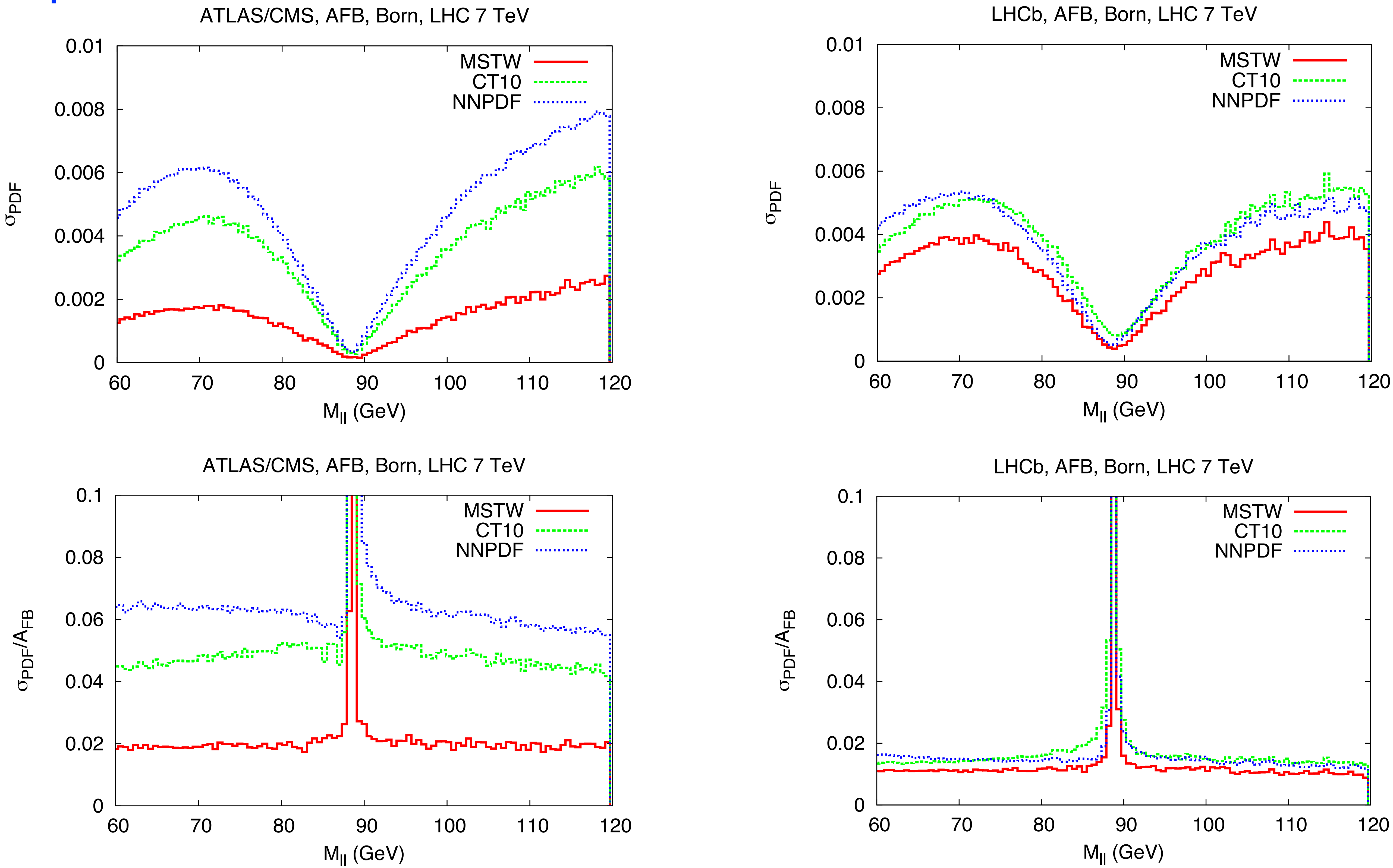


stronger asymmetry at LHCb

the asymmetry vanishes for $M_{ll} \simeq 88.5\,\mathrm{GeV}$

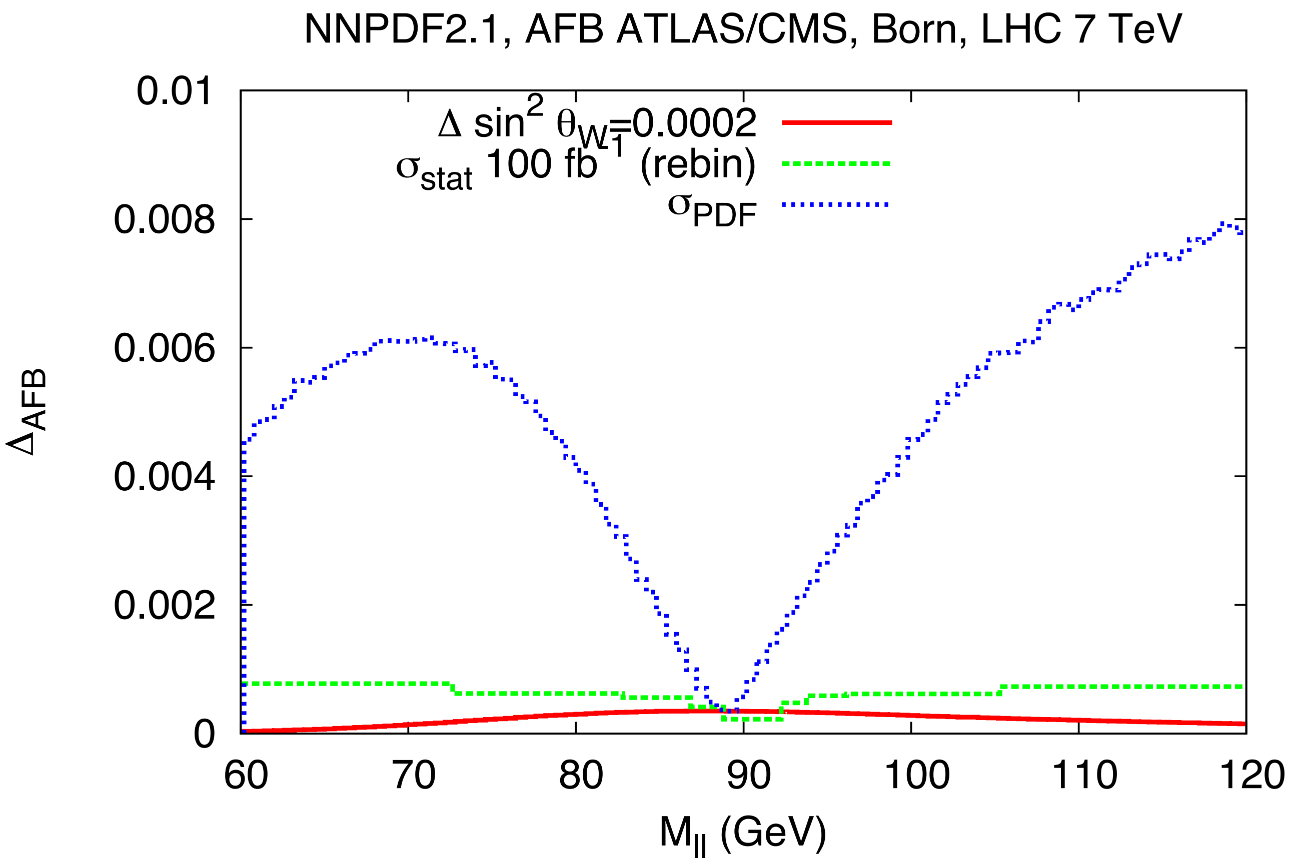
region of maximal sensitivity to $\sin^2\theta_W$ around MZ, i.e. where A_{FB} is still small

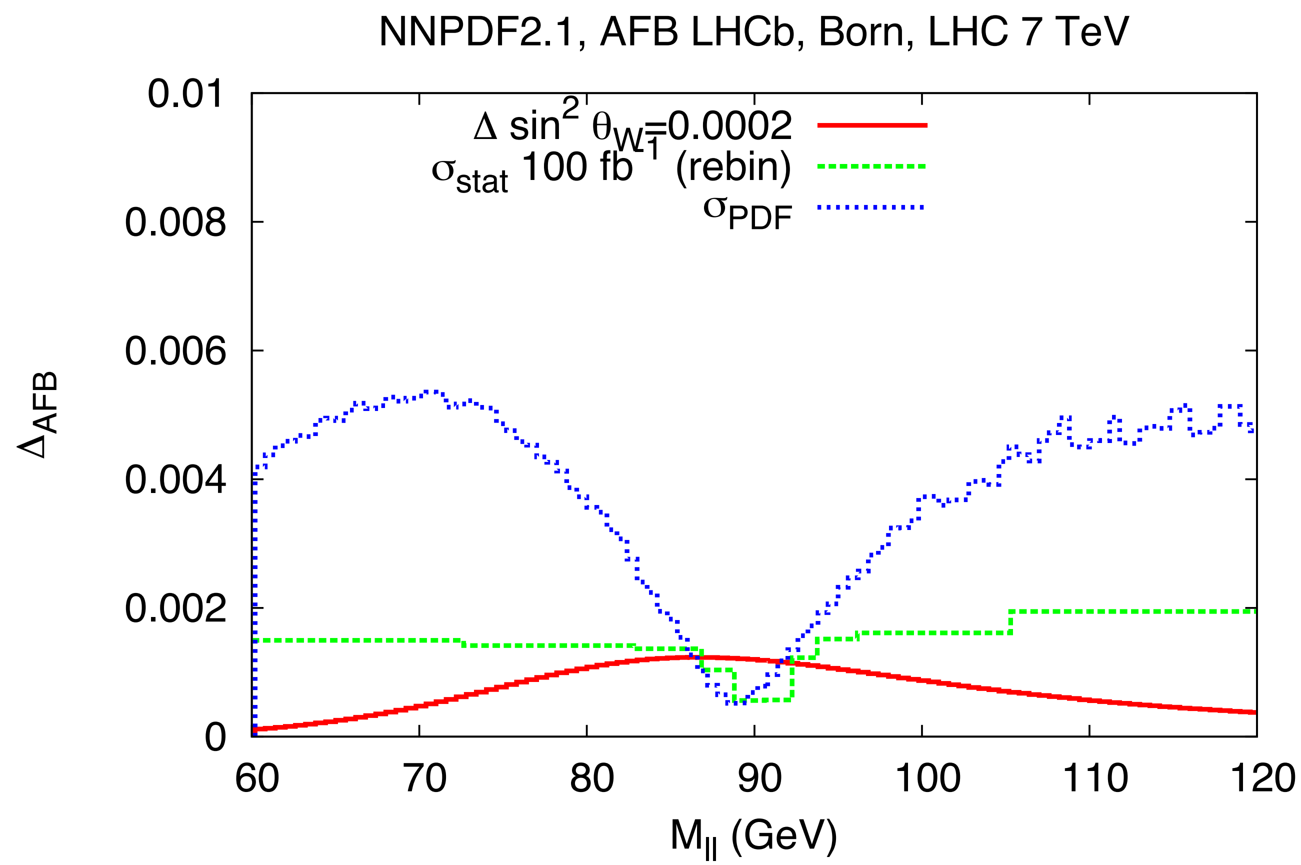
Impact of PDF uncertainties on sin2thetaW measurement



- The relative error is almost constant for all invariant masses (below 120 GeV)

Impact of PDF uncertainties on sin2thetaW measurement

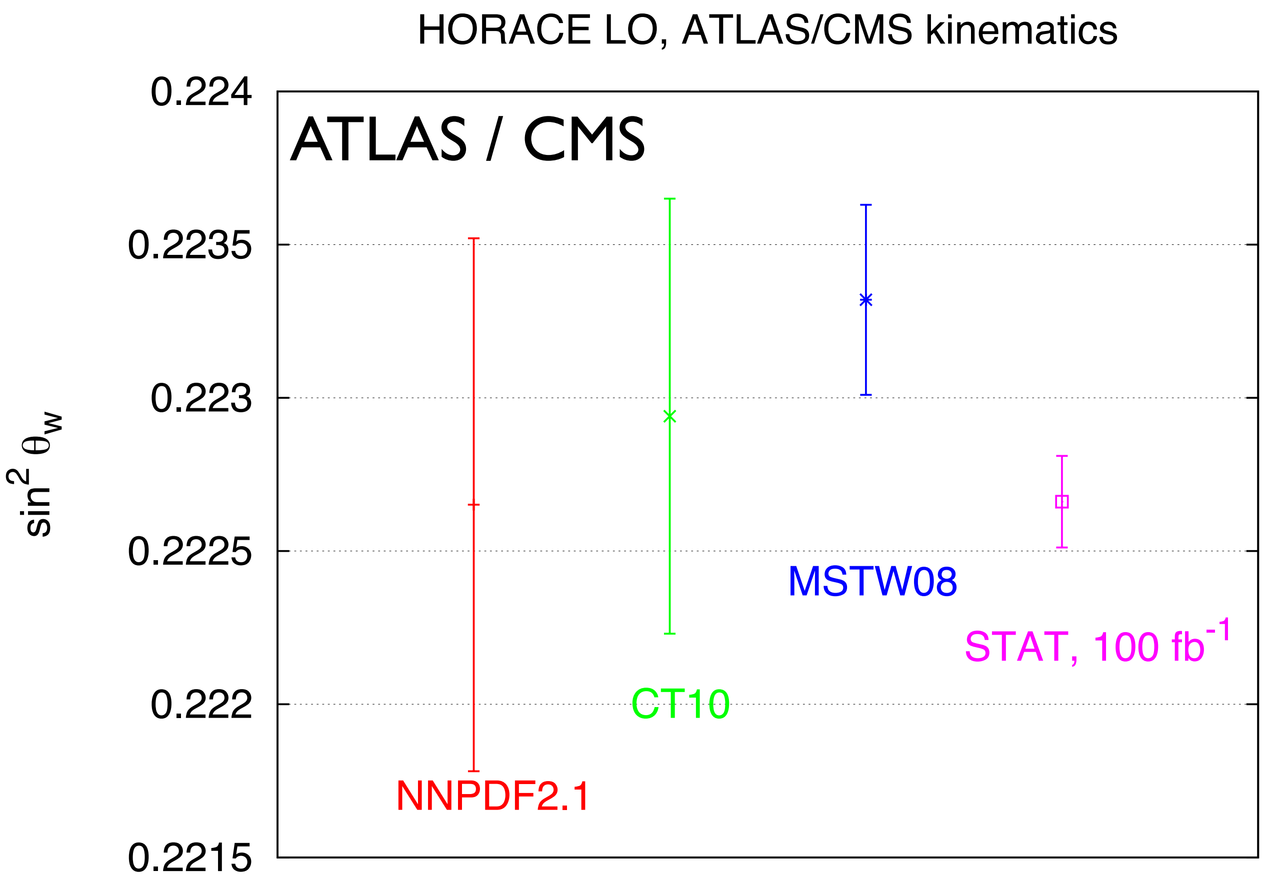


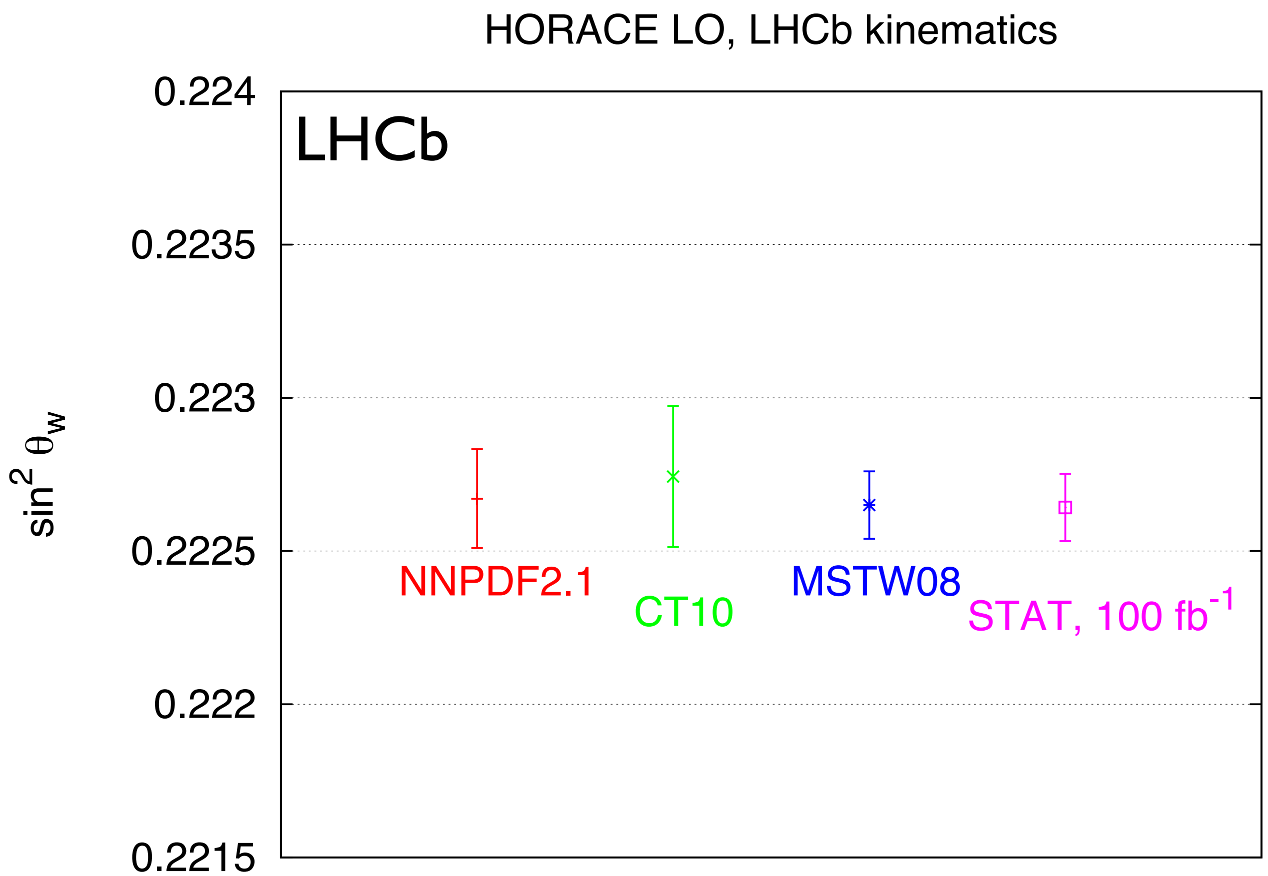


- the PDF uncertainty dominates over the statistical one (after rebinning)
- at LHCb the larger asymmetry implies a stronger sensitivity to sin2thetaW

Impact of PDF uncertainties on sin2thetaW measurement

- applying a template fit procedure,
  the preferred sin2thetaW associated to each replica has been determined





- spread of central values: (max-min)

$$\Delta \sin^2\theta_W = 0.0007 \quad \text{ATLAS/CMS}$$
$$\Delta \sin^2\theta_W = 0.0001 \quad \text{LHCb}$$

- envelope of PDF unc. bands: (max-min)

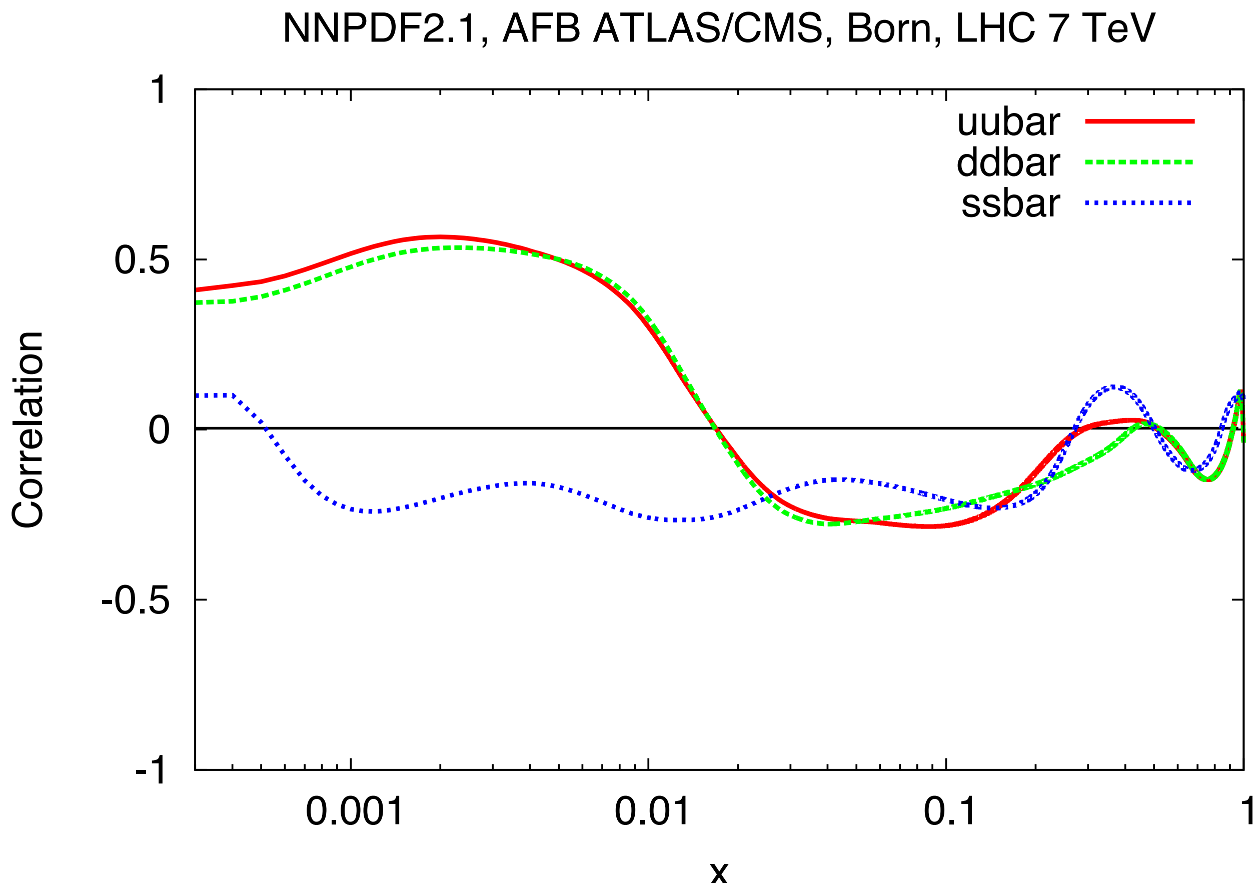
$$\delta \sin^2\theta_W = 0.0019 \quad \text{ATLAS/CMS}$$
$$\delta \sin^2\theta_W = 0.0005 \quad \text{LHCb}$$

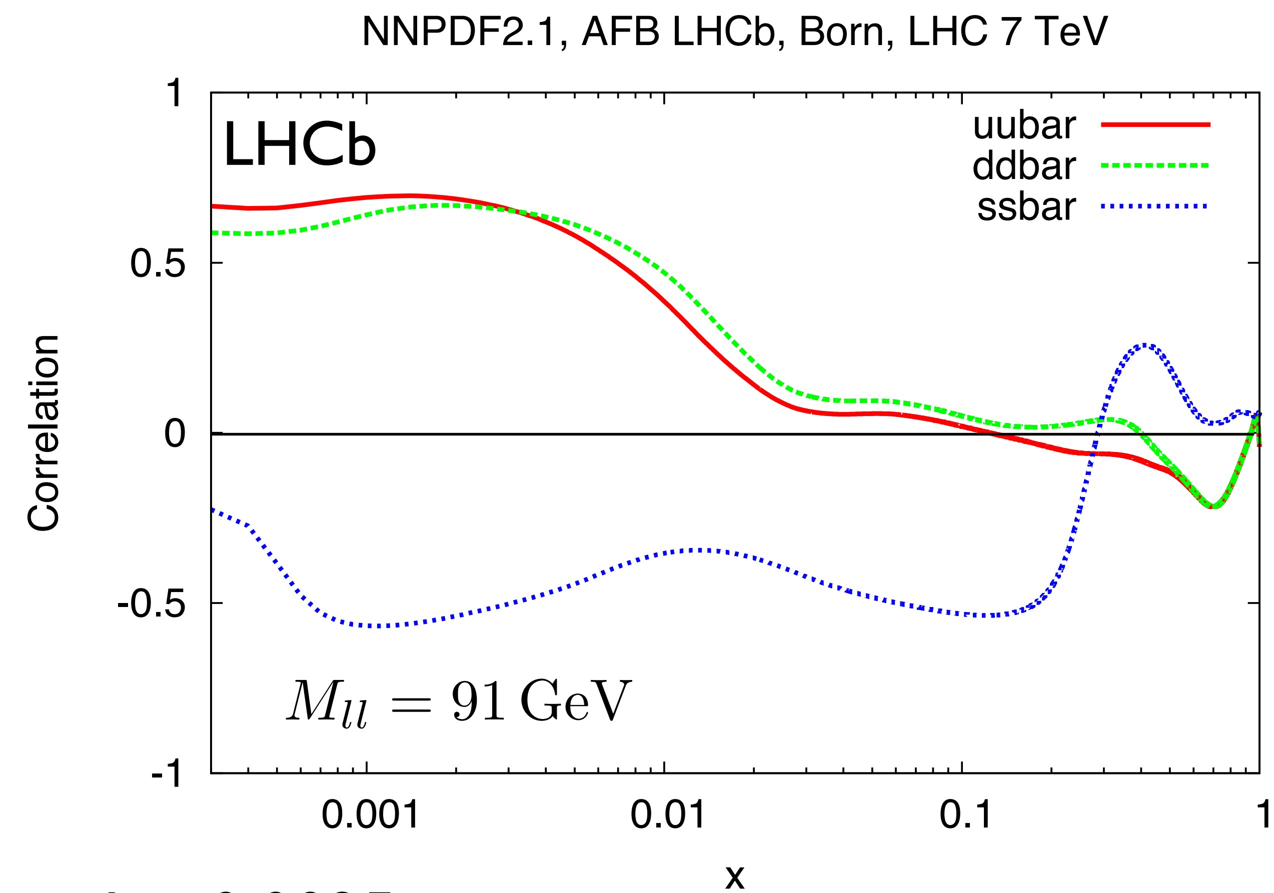
- statistical unc.(100fb-1):

$$\delta \sin^2\theta_W = 0.00015 \quad \text{ATLAS/CMS, LHCb}$$

Correlation of A_{FB} with the parton luminosities

$$\rho\left[A_{FB}(M_{ll}^2),\ q(x)\bar{q}(\tau/x)\right] = \frac{\langle A_{FB}(M_{ll}^2)\ q(x)\bar{q}(\tau/x)\,\rangle_{rep} - \langle A_{FB}(M_{ll}^2)\,\rangle_{rep}\langle q(x)\bar{q}(\tau/x)\,\rangle_{rep}}{\sigma_{PDF}^{A_{FB}}\ \sigma_{PDF}^{q\bar{q}}}$$





- At ATLAS/CMS the x distribution is peaked around x=0.0025
  At LHCb the x_1 and x_2 distributions are peaked around x_1=0.2 , x_2=0.0006
- The asymmetry is mostly due to the role of the valence component of quarks:
  valence quarks boost the event to large rapidities ➔ positive correlation with (u-ubar, d-dbar)
- The s-sbar and sbar-s processes are (almost) identical:
  (almost) cancel in the numerator but are present in the denominator of AFB and reduce the asymmetry ➔ s-sbar is anti-correlated

➔ A precise measurement might help to constrain the up and down densities

The momentum fraction distributions at ATLAS/CMS and at LHCb